

## AN ELECTRIC POWER PLANT

### Technical field

- The present invention relates to an electric power plant comprising at least one
- 5 electric machine of alternating current type designed to be connected directly to a distribution or transmission network and comprising at least one electric winding. The invention also relates to procedures in such a plant.

### Background art

- 10 The electric machine included in the plant according to the invention may be a rotary electric machine such as a synchronous machine, dual-fed machine, asynchronous static current converter cascade, external pole machine or synchronous flow machine, or a stationary machine such as a transformer or a reactor.
- 15 To connect machines of this type to distribution or transmission networks, in the following referred to as power networks, transformers have hitherto been used to step up the voltage to network level, i.e. to the range 130-400 kV.

- Generators having a rated voltage of up to 36 kV are described by Paul R. Siedler
- 20 "36 kV Generators Arise from Insulation Research", Electrical World, 15 October 1932, pages 524-527. These generators comprise windings of high-voltage cable in which the insulation is divided into different layers with different dielectric constants. The insulating material used consists of various combinations of the three components mica-foil mica, varnish and paper.

- 25 It has now been found that, by manufacturing the above-mentioned winding of the machine from an insulated high-voltage electric conductor with a solid insulation of a type similar to that used in cables for power transmission, the machine voltage can be increased to such levels that the machine can be connected directly to any
- 30 power network without the use of intermediate transformers. The transformer may thus be omitted. A typical operating range for these machines is 30 to 800 kV.

- In conventional generators auxiliary power for starting and operating the machines, as well as for station requirements such as operating pumps and flood
- 35 gates as well as for heating and lighting purposes, is taken via transformers from the generator terminals, the terminal voltage then being less than 25 kV. Figure 1 shows a simplified survey diagram for auxiliary power distribution in a power station according to known technology. Four alternative supply routes to an auxiliary power busbar 200 are illustrated. Two generators G1, G2 are thus connected to a

power network, each via its own transformer 202, 204. Branches to auxiliary power transformers 206, 208 are located outside the generator circuit breakers 210, 212. Auxiliary power is thus diverted through these auxiliary power transformers 206, 208 to the auxiliary power busbar 200. The figure also shows a diesel generator 218 and supply from the local distribution network, for instance, at 220, providing two more supply alternatives to the auxiliary power busbar 200. The distribution of auxiliary power from the auxiliary power busbar 200 is then effected via the alternating current distribution busbars 222 and direct current distribution busbars 224, as described below.

10 Figure 2 shows a modification of the auxiliary power distribution illustrated in Figure 1, also with four supply alternatives. Two of the supply alternatives comprise generators 226, 228 with extra stator windings for auxiliary power generation and excitation 230, 232 and 234, 236, respectively. In both embodiments according to 15 Figures 1 and 2, switching between various supply alternatives entails a temporary voltage interruption on the auxiliary power busbar 200.

In conventional plants, thus, auxiliary power is often taken from the generator terminals via transformers, the terminal voltage then being less than 25 kV. Typical auxiliary power voltages are 400 V - 690 V, 3.3 kV, 6.6 kV, 6 kV - 10 kV. Thus 20 the voltage from the terminal voltage of the generator is often transformed to one or more of these discrete levels via at least one transformer for the auxiliary power.

25 Auxiliary power equipment for heating and lighting, for instance, often requires a voltage of 380-220 V, in which case the power system comprises at least one local power transformer for stepping down the voltage from generator voltage to this auxiliary power voltage. Alternatively an auxiliary power winding may be arranged in the power transformer to perform this stepping down. Both these alternatives 30 for auxiliary power generation require extra equipment in the form of either an extra transformer or a complicated power transformer construction, thus increasing the space required and also making the electric power plant more expensive.

The problems mentioned above are accentuated in electric machines with a terminal voltage in the range of 36-800 kV. 35

The object of the present invention is thus to provide an electric power plant comprising at least one electric machine of alternating current type that can be connected directly to distribution or transmission networks, which power plant also

comprises auxiliary power means enabling the requisite auxiliary power to be provided in a simple manner.

Summary of the invention

- 5 This object is achieved with an electric power plant of the type described in the introduction, having the features defined in claim 1.

The insulating conductor or high-voltage cable used in the present invention is flexible and is of the type described in more detail in WO 97/45919 and  
10 WO 97/45847. The insulated conductor or cable is described further in WO 97/45918, WO 97/45930 and WO 97/45931.

Thus, in the device in accordance with the invention the windings are preferably of a type corresponding to cables having solid, extruded insulation, like those cur-  
15 rently used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strands, an inner semi-conducting layer surrounding the conductor, a solid insulating layer surrounding this semiconducting layer and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important  
20 property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cables which are bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in  
25 diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature of the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent  
30 and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting  
35 layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in the radius of the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the

elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples.

- 5 Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having a resistivity within the range of  $10^{-1}$ - $10^6$  ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.
- 10 The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentane (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.
- 15 The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.
- The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.
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- 25 Ethylene-vinyl-acetate copolymer/nitrile rubber, butylmp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

- Even when different types of material are used as base in the various layers, it is desirable that their coefficients of thermal expansion are of the same order of magnitude. This is the case with the combination of the materials listed above.
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- The materials listed above have relatively good elasticity, with an E-modulus of  $E < 500$  MPa, preferably  $< 200$  MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.
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The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding composed of these layers will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

- 15 According to an advantageous embodiment of the plant in accordance with the invention, at least two adjacent layers of the machine's winding have substantially equally large coefficients of thermal expansion. Damage due to crack formation or the like in the insulating layer is thus avoided.
- 20 According to another advantageous embodiment of the plant in accordance with the invention, said layers are arranged to adhere to each other even when the insulated conductor is bent. This ensures good contact between the layers throughout.
- 25 According to an advantageous embodiment of the machine in accordance with the invention, the auxiliary power means comprise at least one auxiliary power source which is connected to an auxiliary power busbar for distribution of auxiliary power, via power electronics equipment to keep the voltage on the auxiliary power busbar constant, the power electronics equipment being provided with a direct
- 30 voltage intermediate link, to which a back-up voltage can be connected if necessary. A battery is suitably connected to the direct voltage intermediate link to supply a predetermined back-up voltage to the direct voltage intermediate link if its voltage level falls below said predetermined level. This reinforcement of the direct voltage intermediate link allows temporary overloads to be dealt with without
- 35 the ordinary supply source becoming overloaded. Voltage and frequency can thus be maintained on the auxiliary power busbar even in the event of temporary interruptions in the ordinary supply. The power electronics equipment can thus be used together with supply sources, such as synchronous/asynchronous generators with constant or varying frequency and voltage, as well as together with

transformers with suitable levels for the secondary voltage. The auxiliary power busbar may also be supplied from a plurality of parallel supply sources.

According to another advantageous embodiment of the plant in accordance with  
5 the invention, the power electronics equipment is arranged for optional control of power flow from auxiliary power generator to auxiliary power busbar or from auxiliary power busbar to auxiliary power generator, or alternatively from auxiliary power winding in a multi-winding machine to auxiliary power busbar or from auxiliary power busbar to auxiliary power winding in a multi-winding machine. The  
10 equipment for auxiliary power generation can then also be used for electric retardation of the electric machine right down to stop. This is a considerable advantage over known technology in which electric retardation is only possible to 5-10 % of the starting speed, after which mechanical braking is required. No such mechanical braking equipment is thus required in accordance with the present invention.

15 According to yet another advantageous embodiment of the plant in accordance with the invention, if the electric machine is a synchronous machine, the field winding of the auxiliary power generator can be short-circuited and its stator side can be supplied with a three-phase voltage having a phase position and a frequency, such that the auxiliary power generator functions as an asynchronous  
20 machine with direction of rotation for maximum braking torque. This asynchronous operation continues until the machine comes to a standstill.

According to further advantageous embodiments of the plant in accordance with  
25 the invention, the field winding of the auxiliary power generator can be short-circuited and at least one stator winding can be supplied with a direct current. In this case a static frequency changer or a separate thyristor current converter for single-quadrant operation is preferably arranged to supply the stator winding with direct current.

30 According to yet another advantageous embodiment of the plant in accordance with the invention, an auxiliary power generator is designed with a pole number suitable for frequency adaption. The auxiliary power busbar may then have multiple inputs, e.g. a directly connected input and an input via one or more frequency  
35 changers. Double inputs enable switching between alternative supply sources without any interruption of the voltage on the busbar.

Brief description of the drawings

To explain the invention more in detail, embodiments of the plant in accordance with the invention, selected by way of example, will now be described in more detail with reference to Figures 3-22 of the accompanying drawings, in which

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Figures 1 and 2 show survey diagrams of the auxiliary power distribution in a power station in accordance with known technology,

Figure 3 shows a circuit diagram for one embodiment of the electric power plant in accordance with the invention, with various auxiliary power sources for supplying an auxiliary power busbar via a direct voltage intermediate link,

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Figure 4 shows in more detail one of the examples in Figure 3 for obtaining auxiliary power,

Figure 5 shows various alternatives for exciting an electric machine in the plant in accordance with the invention,

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Figure 6 illustrates a principle solution for obtaining auxiliary power in a case with several parallel supply sources,

Figure 7 shows a modification of the embodiment in Figure 6, in which another supply source has been added in the form of an earthing transformer with an extra secondary winding,

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Figure 8 shows in more detail an example of the output circuit of the power electronics equipment in the embodiments illustrated in the previous figures,

Figure 9 shows an embodiment in which auxiliary power is generated by an auxiliary power generator which can also be used for electric retardation of the electric machine,

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Figure 10 illustrates an embodiment having several possible inputs to the auxiliary power busbar,

Figure 11 shows an embodiment having auxiliary power distribution with several voltage levels,

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Figures 12 and 13 show two examples of short-circuiting of the field winding of the auxiliary power generator during retardation,

Figure 14 shows an embodiment of the plant in accordance with the invention, in which a separate auxiliary power generator is used for starting the static frequency changer,

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Figure 15 shows an embodiment in which a separate auxiliary power winding is used for starting the static frequency changer of a synchronous machine,

- Figure 16 shows an embodiment of the plant in accordance with the invention in which a separate auxiliary power winding is used for frequency changer start of a synchronous machine and in which voltage adjustment is performed with the aid of a three-winding transformer,
- 5 Figure 17 shows an embodiment having two generators with common frequency changer equipment,
- Figure 18 illustrates a principle solution for auxiliary power distribution in an embodiment of the plant in accordance with the invention having generators with variable speed,
- 10 Figure 19 shows a schematic view, in perspective, of a section taken diametrically through a stator in a rotary electric machine in an electric power plant in accordance with the invention,
- Figure 20 shows a cross section through an insulated conductor used for windings in machines in the electric power plant in accordance with
- 15 the present invention,
- Figure 21 shows schematically a sector of a rotary electric machine in the electric power plant in accordance with the invention, and
- Figure 22 shows a sector of the stator corresponding to one tooth pitch of the radial sector in Figure 21.

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#### Description of preferred embodiments

- Figure 3 shows a circuit diagram for one embodiment of the electric power plant in accordance with the invention, comprising a number of electric machines of alternating power type, such as generators 2, 4, 6 and a transformer 8, constructed in
- 25 accordance with the invention for connection directly to a busbar at high voltage, typically in the range 40-400 kV via a circuit breaker 9 connected to the power network. The generator 2 is designed with a separate auxiliary power winding 10 for connection via power electronics equipment to an auxiliary power busbar lying typically at a voltage of 400 V. The power electronics equipment comprises an input
- 30 step 12 in the form of a rectifier 12, which is connected between the auxiliary power winding 10 and a direct voltage intermediate link 14. Between the direct voltage intermediate link 14 and the auxiliary power busbar is an output step 16 in the form of an inverter and a transformer 18. The input step 12, direct voltage intermediate link 14 and output step 16 in principle constitute a static frequency
- 35 changer with a constant direct voltage intermediate link.

The generator 4 is provided with a tapping terminal which is connected via transformer 20 and input step 22 to the direct voltage intermediate link 14 for tapping off auxiliary power.



The generator 6 is arranged to drive a separate auxiliary power generator 24 which in its turn is connected to the direct voltage intermediate link 14 via an input step 26.

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By way of another example of an auxiliary power source an earthing transformer 8 is shown connected directly to the busbar and provided with an extra secondary winding 28 for extraction of auxiliary power. The secondary winding 28 is connected to the direct voltage intermediate link 14 via an input step 30.

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A back-up circuit in the form of a battery 32 is connected to the direct voltage intermediate link 14 via a semiconductor rectifier 34 which blocks the circuit during normal operation, and a resistor 36. If the ordinary supply sources for the input steps 12, 22, 26, 30 are limited to keep the output voltage of the static frequency

15 changers constant at temporary overloading and temporary cuts in the supply, the back-up circuit 32, 24, 26 comes into operation and maintains constant voltage on the direct voltage intermediate link 14. This avoids the supply source(s) being overloaded at temporary overloading or interruptions. The back-up circuit 32, 34, 36 thus serves to reinforce the direct voltage intermediate link 14.

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In system solutions having several parallel inputs, like the supply of the direct voltage intermediate link 14 shown in Figure 3, equipment for load distribution may also be included.

25 At maximum permitted current in the input the output voltage levels on the input steps 12, 22, 26, 30, i.e. the voltage on the direct voltage intermediate link 14, shall be lower than the level of the back-up voltage of the back-up circuit 32, 34, 36, which is then connected.

30 The auxiliary power busbar may also have several parallel inputs, i.e. a diesel-driven generator 38 and an external supply source connected via the transformer 40, as well as the input 16, 18 from the direct voltage intermediate link 14.

Figure 4 shows more clearly an embodiment with an electric machine in the form

35 of a synchronous machine 42 having an extra auxiliary power winding 44. The voltage from the auxiliary power winding 44 is rectified in the input step 46 of the power electronics equipment. The direct voltage intermediate link of the power electronics equipment 48 acquires a load-dependent voltage value ULS, which is

visualised as a constant voltage  $U$  minus a load-dependent voltage drop  $\Delta U_{RL}$  over the resistor  $R_1$  and the inductance  $L$ .

The direct voltage intermediate link 50 also constitutes a back-up circuit in the form of a battery 52, a semiconductor rectifier 54 and a resistor 56, connected as described above with reference to Figure 3.

At maximum permitted current,  $I_{max}$ , in the supply circuit 58 from the auxiliary winding 44, the voltage level  $U_{LS}$  on the direct voltage intermediate link 50 is less than the level of the back-up voltage  $U_B$  from the back-up circuit 52, 54, 56, whereupon this is connected in via the semiconductor rectifier 54.

The back-up circuit is kept charged via the resistor 56 and the circuit is blocked during normal operation by means of the semiconductor rectifier 54.

If voltage and frequency are constant the input step 46 can be formed by a traditional diode bridge and the load-dependent voltage drop  $\Delta U_{RL}$  is achieved with the aid of the resistor  $R_1$  and inductance  $L$ . In system solutions in which the supply voltage can vary both in level and in frequency, the input step 46 is preferably realised with the aid of controllable semiconducting elements and the voltage level  $U_{LS}$  on the direct voltage intermediate link 50 is adjusted to the current operating situation by means of current-controlled voltage control. Maintenance charging of the battery 52 in the back-up circuit is effected using conventional equipment for charging batteries, and the semi-conductor rectifier may be replaced with a thyristor switch, for instance, having ignition circuit for controlled activation of the back-up circuit.

Voltage conversion and filtering of the harmonic content occurs in the output step of the power electronics equipment 48, comprising an attenuator 60 and transformer 62, as described in more detail with reference to Figure 8.

The auxiliary power distribution normally comprises an alternating voltage busbar 64 and one or two direct voltage busbars 66, 68. The direct voltage busbars 66, 68 are supplied by battery 70, 72 and by inverter 74, 76. The inverter 74, 76 can be supplied from the alternating voltage busbar 64 or from the intermediate link 50 of the power electronics equipment 48.

Figure 5 shows an embodiment similar to that shown in Figure 2, with a different supply alternative for excitation of the machine 42. The extra auxiliary power

winding 44 is utilized as supply source for the excitation. It is then important that the field winding 74 of the machine 42, or the supply field, is galvanically separated from the supply source of the excitation equipment.

- 5 Excitation may be performed with the aid of traditional static current converter equipment, a separate synchronous machine or permanent magnet generator 76, or supply from the auxiliary power busbar 64 being used instead of the auxiliary power winding 44.
- 10 Alternatively, excitation can be achieved from the direct voltage intermediate link 50 with the aid of a chopper connection 78 with galvanic separation of input and output.

- The type of supply selected for excitation of the machine 42 depends primarily on the strength of excitation desired. Supply from the auxiliary power busbar 64 is normally not chosen in cases where strong excitation is desired.
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- Figure 6 shows an embodiment similar to that in Figures 2 and 3, in which auxiliary power is supplied to the direct voltage intermediate link 50 through several parallel inputs 58, 78, 80. Two alternatives for excitation of the machine 42 are illustrated in the figure, i.e. from the auxiliary power winding 44 and from the direct voltage intermediate link 50. If redundancy is required it is advisable for two alternatives to be used for the excitation.
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- In the embodiment shown in Figure 6, thus, the power electronics equipment comprises several parallel input steps 58, 78, 80. If galvanic separation is required between the supply sources, a transformer is added to each input step. Individual, current-controlled, voltage regulation of each input step is required if current limiting is necessary for protection of one or more supply sources. In this embodiment the input circuits from the various supply sources are supplied with both varying voltage level and varying frequency.
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- Figure 7 shows another embodiment having several parallel inputs to the direct voltage intermediate link 50, as in Figure 6, one of these input sources comprising an earthing transformer 82 with extra secondary winding 84. The primary task of the earthing transformer 82 is to achieve an artificial zero point for system earthing in order to eliminate circulating third harmonic currents during operation of one or more parallel generators 42, 86, 88, and to limit the zero-point current in the event of external faults.
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The figure shows two supply alternatives from transformer 82, ALT 1 or ALT 2, respectively. In ALT 1 supply is via the direct voltage intermediate link 50, whereas in ALT 2 the auxiliary power busbar 90 is supplied directly from the secondary winding 84 of the earthing transformer 82. In this case the voltage from the secondary winding 84 must be adapted to the voltage on the auxiliary power busbar 90.

Figure 8 shows in more detail an embodiment of the main circuit of the power electronics equipment, comprising input steps connected between a supply source and the direct voltage intermediate link 50 which acts as collection point. As described above, a back-up circuit consisting of battery 52, semiconductor rectifier 54 and resistor 56 is connected to the direct voltage intermediate link 50, and an output step is connected between the direct voltage intermediate link 50 and the auxiliary power busbar, for voltage conversion and filtering harmonics. The input steps, intended primarily for rectifying the voltage from the supply source, and the output step, intended for inverting the voltage, are known per se and are therefore not described in detail.

Figure 9 shows an embodiment of the plant in accordance with the invention in which the equipment for auxiliary power generation can also be used for electric retardation of the machine, the braking effect functioning all the way down to a standstill.

The plant thus comprises an electric machine 92 with brushless excitation and an auxiliary power generator 94, also with brushless excitation. The auxiliary power generator 94 is connected to an auxiliary power busbar 98 via a static frequency changer 96. Other supply sources, such as an external source at 100 or a diesel generator 102, may also be connected to the auxiliary power busbar 98.

A common rotating excitation equipment 104 is provided for excitation of the machine 92 and the auxiliary power generator 94. This excitation equipment comprises a permanent magnet generator 106 and rectifier elements such as thyristor bridges 108, 110 to supply the field windings 112, 114 of the generators 92, 94. The thyristor bridges 108, 110 are controlled from a stationary control means 116, each via its own unit for wireless communication. Each communication unit comprises a stationary transmitter and/or receiver unit 118 connected to the control means 116, and a receiver and/or transmitter unit 120 applied on the rotating excitation equipment.

In Figure 9 a connection 122 is also indicated between the machine 92 and the control means 116, so that the output voltage of the machine 92 can be controlled by control of the excitation. A connection 124 is also indicated to measure the  
5 network voltage, which is necessary for phasing in the machine 92.

In this embodiment the equipment for generating auxiliary power comprises frequency changer equipment 96 for multi-quadrant operation, and can be used for electric retardation of the machine 92. The braking effect is achieved by short-  
10 circuiting the field winding 114 of the auxiliary power generator 94 and supplying its stator side with a three-phase voltage having a phase position and a frequency enabling the auxiliary power generator 94 (synchronous machine) to function as an asynchronous machine with rotation direction for maximum braking torque. Asynchronous operation may continue until the machine 92 comes to a complete  
15 standstill. This is described in more detail below with reference to Figure 12.

The braking effect can also be achieved by short-circuiting the field winding 114 of the auxiliary power generator 94 and supplying its stator winding with direct current, as is described in more detail below with reference to Figure 13.  
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Decisive for how the auxiliary power generator 94 can be used for retardation is how long it can be overloaded without damage.

Figure 10 shows an example of several input possibilities to the auxiliary power  
25 busbar 126. Besides an external supply source 128 and diesel generator 130, for instance, two generators 132, 134 sharing common frequency changer equipment 136 are shown which can in its turn connect the auxiliary power generators 132, 134 (via transformer 138) to the auxiliary power busbar 126. Thus supply via the frequency changer 136 or by directly connected supply from the auxiliary power  
30 generators 132, 134, as well as alternative supplies 128, 130 are possible.

Figure 11 shows an embodiment with auxiliary power distribution having several voltage levels. The generators 140, 142 may thus be connected directly to a 6 kV level and, via transformers 144, 146 with extra secondary lines, directly with the  
35 auxiliary power busbar 150, or via the frequency changer equipment 148. The auxiliary power busbar lies typically on 0.4 kV and supplies the direct voltage busbars 156, 158 via converters 152, 154 as described above. However, other voltage levels, or even several voltage levels, are also possible.

- Figure 12 illustrates more clearly the principle of short-circuiting the field winding 162 of the auxiliary power generator during retardation operation. The field winding 162 is thus connected to the excitation equipment 164 via a thyristor short-circuiter 166 comprising two oppositely directed thyristors 168, 170 with their ignition circuits 172, 174. The stator side of the generator 160 is supplied with alternating voltage via the frequency changer 176 with a phase position and frequency so that the machine operates as an asynchronous machine with direction of rotation for maximum braking torque.
- 10 Figure 13 shows an alternative embodiment in which the generator 160 is supplied with direct voltage on the stator side from a thyristor converter 178. Counter-current braking is thus obtained, where the braking effect is realised with direct voltage.
- 15 Figure 14 shows an embodiment of the plant in accordance with the invention in which a separate auxiliary power generator G2 is used as start motor. The auxiliary power generator G2 is driven by the electric machine G1 which is connected directly to the power network. The auxiliary power busbar 240 lies typically on a voltage of 0.4 kV and has three input alternatives, i.e. a diesel generator Gd, an
- 20 input from an external supply source 241 via a transformer T2, and the separate auxiliary power generator G2 which is connected to the auxiliary power busbar 240 via a transformer T1 for voltage adjustment. At the moment when the machine G1 is to start, the circuit breakers CB1, CB2 and CB5 are opened. A voltage is applied on the auxiliary power busbar 240 via one of said supply alternatives
- 25 Gd, 241. During the time for the first step of the start-up process the circuit breaker CB4 is closed and the circuit breaker CB5 is open, which means that the frequency changer FC is connected directly to the auxiliary power generator G2. During the time for the second step of the start-up process the circuit breaker CB4 is open and the circuit breaker CB5 is closed. During the start-up process the exci-
- 30 tation equipment EXC of the auxiliary power generator G2 is supplied from the auxiliary power busbar 240 via the transformer T3. When the machine G1 has been phased in in motor operation, switching occurs to ordinary excitation and voltage is applied on the auxiliary power busbar 240 from the external network by supply via machine G1 and auxiliary power generator G2. The circuit breaker CB1
- 35 is closed and the other auxiliary systems can be started.

Figure 15 shows an alternative embodiment of the plant in accordance with the invention, in which a separate auxiliary power winding 242 of the machine G1 is used at start-up. In a similar manner to the embodiment described in Figure 14,

- the auxiliary power busbar 240 has three input alternatives, of which one supply source is the separate auxiliary power winding 242 of the machine G1 which supplies the auxiliary power busbar 240 via the transformer T1 for voltage adjustment. The start-up process is the same as in the embodiment shown in Figure 14 and, when the machine G1 has been phased in in motor operation, switching occurs to ordinary excitation by the excitation equipment EXC and voltage is applied on the auxiliary power busbar 240 from the external network through the machine G1 and its auxiliary power winding 242. When the synchronous machine G1 has been phased in it can have the following simultaneous operating modes: A synchronous motor mode for driving a turbine part, for instance, in air or vacuum, a synchronous compensator mode for generating reactive power for maintaining voltage, and a transformer mode for stepping down and transmitting both active and reactive power to the auxiliary power busbar.
- Figure 16 shows a modification of the embodiment in Figure 15, in which a three-winding transformer 244 is connected to the auxiliary power winding 242 of the machine G1. The auxiliary power busbar 240 is supplied via one secondary winding of the three-winding transformer 244 and the transformer 243, while the other secondary winding of the three-winding transformer 244 is used for excitation of the machine G1. The start-up process, as well as normal operation are performed in a similar manner as in the embodiment according to Figure 15.

- Figure 17 shows an embodiment of the plant in accordance with the invention, with two machines or generators 246, 248 having common frequency changer equipment FC for start-up. Each generator 246, 248 comprises an extra auxiliary power winding 250, 252 to supply the auxiliary power busbar 254 in a similar manner as in the embodiment in Figure 15. The auxiliary power systems can be connected with the circuit breaker CB7 and the auxiliary power windings can be separated from respective auxiliary power busbar 254 with the aid of circuit breakers CB1, CB4, respectively. The figure also shows turbine parts ST1 and ST2 connected to the machines 246, 248 via couplings C1, C2, respectively. In other respects the function of the embodiment shown in Figure 17 is the same as that of the embodiment shown in Figure 15.

- Figure 18 illustrates yet another principle for auxiliary power distribution when the speed of the machines 256, 258 in the plant is variable. A voltage is applied on the auxiliary power distribution at station level via one of four alternative input routes, i.e. from either the machine 256 or the machine 258, or from a diesel generator 260 or from an external supply source 262. At start-up of the machine 258,

voltage is applied temporarily on the auxiliary power distribution for the machine 258 via the auxiliary power distribution for station level, whereupon the ordinary input from the machine 258 is opened before applying voltage. After start-up and voltage build-up, switching occurs to ordinary excitation, i.e. the machine 258 produces its own auxiliary force. Constant speed is maintained for pump driving and the like upon variation in the voltage and frequency of the supply network, with the aid of integral motors 264. Direct voltage and alternating voltage distribution busbars are connected to the auxiliary power distribution at station level as described above. The alternative voltage distribution busbar given priority is supplied via frequency changers 266, 268 by constant direct voltage intermediate link 270 and battery back-up 272, as described above.

Several modifications of the embodiments shown and described above by way of example are feasible within the scope of the invention. Thus, both auxiliary power generator and machine can be excited with the aid of static exciters or brushless exciters with diode rectifiers. Furthermore, adaptation and coupling between auxiliary power generators and auxiliary power busbars can naturally be realised in several different ways. Start-up methods and principles may vary from plant to plant, and in some cases the frequency changer may be supplied for start-up from a separate supply source, possibly from a separate diesel generator.

The conductors and other equipment for auxiliary power generator can also be used for electric braking as well as frequency changer start of the machines.

Figure 19 shows a part of an electric alternating current machine of the type included in the plant in accordance with the invention. The rotor has been removed to reveal the construction of the stator 1 more clearly. The main parts of the stator 1 are a stator frame 25, a stator core 3 comprising stator teeth 27, and a stator back defining an outer back portion 5. The stator also comprises a stator winding 29 formed from an insulated conductor and placed in a space 7, also termed slot, shaped like a bicycle chain, see Figure 21, formed between individual stator teeth 27. In Figure 21 the stator winding 29 is only indicated by its conductor. As is apparent from Figure 19, the stator winding 29 forms a coil-end package 31 on each side of the stator 1. Figure 21 also reveals that the insulated conductor is stepped in several dimensions, depending on its radial position in the stator.

In larger conventional machines, the stator frame 25 often consists of a welded steel plate construction. In large machines the stator core 3, also termed the laminated core, is generally made of 0.35 mm plate divided into stacks with an axial



length of approximately 50 mm separated from each other by 5 mm ventilation ducts forming partitions. However, the ventilation ducts are eliminated in a machine of the type included in the plant in accordance with the present invention. In large machines the construction of each laminated stack is achieved by stacking  
5 punched plate segments 9 of a suitable size together to a first layer, and placing each subsequent layer crosswise to construct a complete plate-shaped part of a stator core 3. The parts and partitions are held together by pressure shanks 33 which are pressed against pressure rings, pressure fingers or pressure segments, not shown. Only two pressure shanks have been shown in Figure 19.

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Figure 20 shows a cross-section through an insulated conductor intended for use in the windings in the machine or machines in the plant in accordance with the present invention. The insulated conductor 11 comprises a number of strands 35 having circular cross section and consisting of copper (Cu), for instance. These  
15 strands 35 are arranged in the middle of the insulated conductor 11. A first semiconducting layer 13 is arranged around the strands 35. An insulating layer 37, e.g. XLPE insulation, is arranged around the first semiconducting layer 13. A second semiconducting layer 15 is arranged around the insulating layer 37. The insulated conductor is flexible and retains this property throughout its service life. Said three  
20 layers are constructed so that they adhere to each other even when the insulated conductor is bent. The insulated conductor has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm<sup>2</sup>.

Figure 21 shows schematically a radial sector of a machine with a segment 9 of  
25 the stator 1 and a rotor pole 39 on the rotor 17 of the machine. It can also be seen that the stator winding 29 is arranged in the space 7 shaped like a bicycle chain, formed between individual stator teeth 27. Each stator tooth 27 extends radially inwards from the outer back portion 5.

Figure 22 shows a sector corresponding to one tooth pitch of the radial sector in Figure 21, with the stator winding 29 in the slot 7, this being made in three steps with the innermost step, seen in radial direction, having the smallest diameter and the outermost step, seen in radial direction, having the largest diameter. Each  
30 step is provided with four winding turns. The slot 7 has a bottom 41 at its outermost radius, and a top 21 at its innermost radius. The embodiment in Figure 22 shows an auxiliary power winding 43 arranged in a channel 23 situated in connection with the bottom 41 of the slot through which the auxiliary power winding 43 runs. Furthermore, the channel 23, with its auxiliary power winding 43 is situated radially in relation to the stator winding 29. The complete auxiliary power  
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winding is obtained by a suitable number of slots 7 being provided with channels 23 in the bottom 20 of the slot so that a suitable number of winding turns is obtained depending on the auxiliary power voltage desired. The location shown in Figure 22 offers advantages as regards assembly of the winding. This location 5 also gives lower losses in the extra winding and ensures that the leakage reactance for the main winding does not increase. The auxiliary power winding is constructed in the same way as the main winding but with considerably fewer turns, which gives lower terminal voltage. The power output from the auxiliary power winding is within the range of a kW or so up to about 25% of the total output of the 10 machine. Thus the auxiliary power winding is the smaller winding with regard to power and is therefore placed in the bottom of the slot 7.

The auxiliary power voltage for the station requirement is determined to certain values, e.g. 400 V-690 V-3 kV, 3 kV-6.6 kV or 10 kV. However, depending on the 15 parameters of the main design of the generator construction, it may not be possible to obtain these specific voltage levels and the auxiliary power winding is therefore dimensioned to come as close as possible to these values so that a transformation to these values can be achieved with a relatively simple transformer.

20 The embodiment of an auxiliary power winding shown in Figure 22 constitutes only one possible solution of the location of the winding. The winding may also be placed in the top 21 of the slot, or somewhere else along the slot. A slot may also be provided with more than one winding turn. Neither need every slot be provided with auxiliary power winding. Instead every second slot, or every third slot may be 25 provided with the winding. Many modifications of the embodiments may therefore be selected within the scope of the invention, depending on the design parameters of the generator and the auxiliary power voltage desired for the station requirements. The common denominator for all embodiments is that the generator is provided with a stator winding of high voltage type and that the auxiliary power winding 30 is located in or close to the slot. By "in or close to" the slot is means that the slot space 7 communicates with the channel 23 for the auxiliary power winding 43.

The stator thus comprises at least one winding system acting as auxiliary power winding consisting of solid insulated conductors of the type described above, 35 placed and arranged so that they link enough magnetic flux to ensure that the induced voltage is suitable for direct connection to a distribution or transmission network, i.e. typically 36 kV - 800 kV.

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